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ABSTRACT

A vast literature in educational psychology attests to the fact that individual differences in learner aptitudes predict learning outcomes. A substantial body of literature also demonstrates that aptitude variables often interact with instructional treatment variables in these predictions. Aptitude main effects and aptitude-instructional treatment interactions (ATI), frequently account for a larger proportion of variation in learning outcome than do treatment main effects alone. ATI findings, in particular, have important implications for the development of instructional theory and research and for instructional improvement. They suggest how instruction can be made adaptive to student differences. But if practical and theoretical use is to be made of these ideas, then individual differences in aptitude for learning need to be understood, at a more analytic level, as individual differences in psychological processes. Traditional research on aptitude sought mainly to improve the predictive power of measures, and to build a taxonomy of aptitude constructs based on correlational and factor analyses. With the growth of a cognitive experimental psychology of information processing, coupled with the development of ATI research on instruction, it now seems possible to pursue coordinated process analysis of aptitude and learning. This paper reviews some of the current research in this area, concentrating particularly on recent and ongoing studies conducted within the Aptitude Research Project at Stanford University. First, two ATI findings are described and then some strategies for research aimed at identifying aptitude processes are outlined. There seem to be five different approaches that have been used to measure aptitudes, and these are described briefly. (Author/AM)

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An Overview of Current Research on Aptitude Processes

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An Overview of Current Research on Aptitude Processes

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A vast literature in educational psychology attests to the fact that individual differences in learner aptitudes predict learning outcomes. A substantial body of literature also now demonstrates that aptitude variables often interact with instructional treatment variables in these predictions (Cronbach & Snow, 1977). Aptitude main effects and aptitude-instructional treatment interactions (ATI), frequently account for a larger proportion of variation in learning outcome than do treatment main effects alone. ATI findings, in particular, have important implications for the development of instructional theory and research and for instructional improvement. They suggest how instruction can be made adaptive to student differences. But if practical and theoretical use is to be made of these ideas, then individual differences in aptitude for learning need to be understood, at a more analytic level, as individual differences in psychological processes. Traditional research on aptitude sought mainly to improve the predictive power of measures, and to build a taxonomy of aptitude constructs based on correlational and factor analyses. With the growth of a cognitive experimental psychology of information processing, coupled with the development of ATI research on instruction, it now seems possible to pursue coordinated process analysis of aptitude and learning.

Current research on these phenomena seeks to understand individual differences in aptitude, learning, and problem-solving as functions of common underlying psychological processes. The goal is a theory of aptitude for instruction that expresses aptitude-learning relations in information processing terms. The combination of experimental and correlational

theory and methodology thus produced is important for both cognitive and psychometric research on aptitude, for ATI research, and for instructional psychology generally.

This symposium reviews some of the current research in this area, concentrating particularly on recent and ongoing studies conducted within the Aptitude Research Project, School of Education, Stanford University, and supported by the Office of Naval Research. First, I will show two ATI findings as examples of the starting point and then outline some strategies for research aimed at identifying what we call aptitude processes. This will provide a framework for the other presentations. The second presentation, by Brachia Marshalek, examines two models of ability organization as a starting point. He presents correlational data on reference abilities to interpret the traditional hierarchical factor model and Guttman's Radex Theory in terms of the complexity of processing called for by different mental tests or tasks. The third presentation, by David Lohman, reports some results on individual differences in eye fixations during performance on a variety of ability test items. Eye fixation indices representing hypothesized cognitive process variables are discussed in relation to reference ability factors. Then, Elanna Yalow will review methods of obtaining introspections from students about strategies and processes they use in performing aptitude and learning tasks. Data showing the relation of introspective strategy indices to eye movement and reference ability factors are reported.

In addition, we are happy to have Lauren Resnick and Robert Sternberg here as critic-discussants, and Bob Calfee, as Chairman, of course also has a license to criticize and discuss.

Background

Aptitudes are individual difference variables that predict learning in a particular situation. The defining characteristic of aptitude, then, is relation to learning. A recent review of research on aptitude (Snow, 1977) suggested two constellations, called "aptitude complexes", into which many of the better substantiated ATI findings seem to fit. One of these centers on the construct of intelligence or general mental ability (abbreviated as G) and its division into verbal-crystallized ability (G_c), fluid-analytic ability (G_f), and spatial-visualization ability (G_v). G appears to interact when instructional

treatments differ in the information processing burden they place on the learner. The other is a complex of anxiety and motivation for achievement via independent work vs. conformity to instructional prescriptions. These variables seem to enter interactions when treatments are more vs. less structured by the teacher. There is reason to believe that the two complexes interrelate, since some investigations show cognitive ability and anxiety entering into higher-order ATI. As a start toward process theory however, the present research concentrates on G.

In sheer numbers, measures of G have shown more ATI in instructional studies than any other aptitude. The weight of this evidence suggests that G relates more strongly to learning outcomes when instruction is described as using elaborate or unusual explanations, including discovery or inquiry methods, encouraging learner self-direction, relying heavily on verbiage, or as relatively unstructured, permissive, or rapidly paced. Thus, in general, it seems that when instruction places the burdens of information organization and processing more on the learner, high ability students do well while low ability students do poorly. On the other hand, the relation of G to learning tends to be reduced when instructional conditions relieve the learner of some information processing burdens by simplifying or breaking down the task, focussing on essentials, giving redundant text or simplified demonstrations and models, or substituting other media for verbiage. In these latter environments then, high ability students often do less well than otherwise, while learning is enhanced for low ability students.

Though many studies have obtained this kind of result, there are exceptions, and even the strongest results are not really well understood. Different studies use different measures of G; the majority of measures used seem more nearly to represent G_c, but others would have to be called G_f. No study has adequately distinguished these two prime constituents of G, so interpretation is unclear on this point. Descriptions of instructional treatments are also gross.

One study that gave this kind of result and also attempted to distinguish G_c and G_f was a dissertation by Sharps (1973). He conducted a large scale field study as an evaluation of Individually Prescribed Instruction (IPI), using fifth grade classes in four schools. There were 134 students who had experienced IPI programs throughout their school years

and 139 control students who had not experienced IPI. Instructional treatments spanned the year. At the start of the year, six aptitude measures from the Cattell Culture Fair Intelligence Scales and the SRA Primary Mental Abilities tests were administered in each classroom. These yielded two composites, one for G_c, the other for G_f. Four of the Iowa Tests of Basic Skills served as the achievement measure at the end of the year. These were: vocabulary, reading comprehension, arithmetic concepts, and arithmetic problem solving.

ATI was clear for G_c, not for G_f, on all outcome measures. Figure 1 shows the regression results for the reading comprehension outcome; a similar pattern was observed on other achievement measures. IPI reduced the relation of G_c to outcome. In so doing, it became a superior treatment for low G_c students but inferior for high G_c students. Treatment main effects were slight. G_f gave little or no interaction. But Sharp's analysis did not go far enough to rule out an interpretation based on G. Correlations among aptitudes were not reported and the two composite aptitudes were not defined statistically. A multivariate analysis using a general factor ($G_c + G_f$) and a contrast factor ($G_c - G_f$) as aptitudes would test whether G, or G_c alone, accounted for ATI.

Insert Figure 1 about here

But the ATI findings stand and G_c, at least, is implicated. The results replicate those of Crist-Whitzel and Hawley-Winne (1976), who found ATI with G_c in another year-long evaluation of IPI in sixth grade mathematics. In their multiple regression analysis, incidentally, G_f produced a similar interaction after the G_c interaction had been removed statistically. (See Snow, 1977, for further discussion.)

IPI is a system of individually-paced instruction relying on specific pretests, geared to carefully specified objectives and sequenced content, with frequent checkpoints as guides and feedback on learner progress, plus mastery tests for each unit. As such it combines many features of the kinds of treatments found in past research to help lower ability learners. The ATI interpretation seems to be that IPI structures the learner's experience in some detail, doing for lower ability students what they may not be able to do for themselves (i.e., compensating for an inaptitude by

removing excess organizational and attentional complexity). In so doing, however, IPI may be dysfunctional for able students, who can organize their own learning; they seem better off with conventional teaching. Whether this dysfunction should be attributed to cognitive interference, or motivational "turn-off", or both, or other factors, is unclear. In any event, ATI analysis demonstrates once again that no one instructional treatment is best for everyone, even one that purports to be individualized.

IPI is a fairly well specified instructional treatment. But what is G_c? It has been interpreted as generalized scholastic achievement, verbal-educational ability, acquired knowledge, informed judgment, awareness of applicable and previously "crystallized" skills and concepts, etc. Lacking a process theory of aptitude, it is difficult to get beyond these traditional trait-like quantitative descriptions. To understand ATI here, we need to understand by what aptitude processes in learning, under each kind of instruction, do strengths and weaknesses in G_c manifest themselves.

An experiment by Loftus and Loftus (1974) concerned retrieval of information from semantic memory; but it shows, at least by analogy, something of the processes that may be represented by G_c aptitude. Subjects were graduate students in psychology who differed in degree of learning experience in graduate school. They were asked to recall the name of a psychologist, given one of six areas of psychology and the first letter of the psychologist's last name. Reaction time was measured for each student under two conditions: letter first, followed by area designation; area first, followed by letter. It was expected that advanced graduate students would show a pattern of results like that often obtained previously with any well-learned categories: reaction time should be faster when the letter follows the area designation, rather than vice versa, because the learner can find the location in his semantic memory structure where the area designation is stored while the restrictive letter is being presented, thereby saving overall time in the two-step retrieval process. Retrieving the name "Piaget", for example, should be faster in response to the stimulus order "Developmental-P" than with the order "P-Developmental".

Figure 2 is redrawn from that given by Loftus and Loftus, since by convention in ATI research aptitude variables are always assigned to the

abscissa. The results show a clear ATI pattern. With advanced graduate students the area-letter order of presentation requires less retrieval time than does the letter-area presentation order. With beginning students the difference between conditions is small, and actually reversed! Relatively inexperienced students--lower in crystallized knowledge of psychology--seem not to possess the kind of organized memory structure held by advanced students.

> The implication is that when a student "learns about" psychology, this learning consists of changing the semantic organization of his knowledge about psychology and/or the process of retrieving information about psychology.
>
> ... [this] suggests a substantial departure from traditional notions about "what is learned" and "what should be tested". In typical educational settings, the student is viewed as learning facts... . It seems reasonable, however, on intuitive, theoretical, and empirical grounds that "what is learned" goes considerably beyond fact acquisition. Indeed, it is the case that the process of learning involves a reorganization of semantic information and implementation of new retrieval schemes.
>
> [Loftus & Loftus, 1976, p. 152]

Insert Figure 2 about here

The reversal for novice graduate students may also make sense. One might speculate that such students learn names frist before gaining a well-organized conception of disciplinary subdivisions. Thus, the letter-first condition allows them to start running through their list of associations early; the area designation then helps them to reduce the list or select from it.

These views seem consistent with those of other cognitive theorists. Rumelhart and Norman (1976), for example, speak of "accretion", "restructuring", and "fine tuning" as three distinguishable stages of the sort of complex learning found in educational settings. There is a stage of fact accumulation, which may produce masses of loosely and simply connected knowledge. At some point these masses must be reorganized into more integrated and formalized (crystallized?) structures, and ultimately sharpened into smoothly useable tools of thought. What is important here, however, is the possibility that the sort of semantic

structure and retrieval differences demonstrated by Loftus and Loftus may be similar to those discernable throughout years of educational development and captured by general scholastic ability and achievement tests, i.e., by measures of G_c.

Again, however, what is needed to push further is a more detailed process description of G that distinguishes G_c, G_f, and G_v.

Process analysis of ability

The cognitive ability tests used to measure G aptitudes are cognitive tasks, not different in kind from the tasks used in cognitive psychology laboratories to study human information processing. Several lines of recent work suggest that ability tests can be analyzed in information processing terms (e.g., Glaser, 1976; Resnick, 1976) and a number of task-specific process models now exist for one or another kind of ability test (e.g., Kotovsky & Simon, 1973; Sternberg, 1977). Correlations also occur with some frequency between test scores and information processing measures (e.g., Hunt & Lansman, 1975; Carroll, 1976).

There seem to be five different approaches that have been used so far, or can be used, in pursuing research on this problem. These are likely to be complementary and to be used in combination at some point. But it is useful at the start to separate them in order to examine their strengths and weaknesses. All approaches begin by choosing one or more aptitude constructs for attention. But each then proceeds by making somewhat different assumptions and using more or less restrictive methodology.

The first two approaches are more distinctly exploratory. They are: (1) the collection of introspective reports by subjects, and (2) the recording of eye movement patterns, both during actual performance on aptitude tests. Computer simulation research has long relied on subject introspections about processing strategies, sequences, and styles, in the form of "think aloud" protocols. These are then used to guide the development of process models, such as computer programs designed to simulate the processes called for by the task(s), and individual differences therein. The Simon-Kotovsky (1963, 1973) work on Thurstone's letter series reasoning task is perhaps the best example of this approach applied specifically to an aptitude measure (but see also Simon, 1976). The advent of modern cognitive psychology, and some recent technological advances, has renewed interest in eye movement tracking during cognitive processing (see, e.g., Monty & Senders, 1976). And Just and Carpenter (1976) have now applied this approach to the study of several test-like cognitive tasks, including mental rotation problems of the sort often

taken as measures of spatial ability. They have shown how eye movement patterns may reflect some of the stages of cognitive processing at a level of detail not possible previously.

These approaches seem particularly well-suited to the exploratory study of individual differences in aptitude processes. While there is little direct prior experience with either technique in this connection, and one can question whether either source of data yields veridical representations of internal mental activities, both introspection and eye tracking can be applied across tasks, and their use in combination may provide a form of construct validation for each.

(3) A third approach is to correlate scores representing some aptitude construct with measures derived from laboratory tasks for which coherent information processing models are already in hand. The Hunt studies (e.g., Hunt and Lansman, 1975) and those of Chiang-Atkinson, (1976), and Carroll (1976) are examples of this approach. Hunt's work in particular yields the hypothesis that verbal-crystallized ability is associated with speed of coding and temporal order operations in short-term memory. We can add this relation to the Loftus & Loftus finding to elaborate our process conception of G_c. But other studies suggest that relationships of this sort are unlikely to be so simple. Chiang and Atkinson (1976) confirmed Hunt's result for males only, finding the opposite trend for females. And further analyses of the Chiang-Atkinson and Hunt data in our laboratory (Snow, 1976; Snow, Marshalek & Lohman, 1976) suggest that, rather than one-to-one correspondences between ability test scores and the parameters of particular information processing tasks, we should expect complex networks of interrelationships, including multiplicative and perhaps curvilinear combinations of variables. Furthermore, process models are required that apply not only to specific tests or tasks but to all tasks purporting to reflect a particular aptitude construct, and they need to be validated in the context of the other aptitude constructs that exist. Thus a method of analysis is needed by which information processing can be examined both within and between tasks, and the construct validity of process model components can be established.

(4) The fourth approach seeks to accomplish this by breaking down the aptitude test(s) directly to obtain measures representing hypothesized component processes involved in individual differences in performance on the test. These component scores are then used to build a process

model to account for within and between task differences, and to correlate model component measures with reference abilities. This is the procedure demonstrated by Sternberg's (1977) work on analogical reasoning, though other forms of this task-analytic approach are represented in the work of Resnick (1976) and others at LRDC-Pittsburgh.

This approach has much to recommend it. It produces a component process model of each aptitude task that can be internally validated within tasks and externally validated between tasks, both within and between aptitude constructs. It does assume, however, that the psychology of the task is not changed by within-subject experimental manipulations, that response latencies for components of each model capture the important features of cognitive processing, and that these component latencies are independent. While the latter assumption is clearly testable (see Sternberg, 1977; also Calfee, 1976), the earlier assumptions remain troublesome. We need to know whether changing the aptitude task, particularly changing it within subjects over long series of trials, creates an artificial or confounded view of individual differences in aptitude processes that differs in important ways from aptitude as measured and related to learning in real instructional situations. The same concern would also apply to similar analysis of learning tasks.

(5) A fifth approach also manipulates information processing tasks experimentally, but the manipulations are designed to alter the relation between an aptitude, conventionally measured, and process measures derived from the experimental task. The manipulation might be within-subjects as in the Loftus & Loftus example, but is more likely to be between subjects to avoid the problem of within-subject confounding alluded to above. This is the approach closest in form to the ATI paradigm for instructional research, but in the laboratory it has more often been referred to as the S-R-R paradigm: stimulus conditions are varied to influence hypothesized cognitive processes intervening between stimulus and response, for example, by deleting a processing step under one experimental condition while including it in another. If the intervening process under manipulation is also present in or represented by the separate aptitude measure, then the R-R relations should differ under the two conditions.

This approach can be thought of as a variant of either the third (Hunt's) or fourth (Sternberg's) approach above, but it has rarely

been used in its between-subjects form (but see Gavurin, 1967 and further discussion by Snow 1976).

Our research project includes or plans to include studies based on all these approaches, and combinations of them. But we began with the first two, exploratory correlational techniques, hoping to obtain an initial mapping of the terrain of individual differences in aptitude processes to guide the more powerful but potentially more artificial and disruptive experimental studies to come later. Today's symposium is concerned with these initial studies.

In addition to the reasoning about these techniques mentioned above, there is another view motivating our choice; we consider it inadequately represented in all of the approaches discussed above but most easily reconciled with the more exploratory approaches. It is the view that one never studies an aptitude construct in isolation. Every aptitude task exists in a conceptual and empirical network of relationships with other tasks. These relationships are there whether represented in any particular study or not. Traditional differential psychology, and particularly its factor analytic tradition, produced a whole storehouse of aptitude constructs relevant to learning, and several structural models to account for the network of persistent relations among different tests and tasks. The factor analytic tradition never produced process models of aptitudes directly, but the correlational properties of the universe of tests and of the organizational models used to structure this universe, do lead to process hypotheses and relationships between them that should not be ignored in future research on aptitude processes. So, we believe these aspects of this prior history should be part of such future research. An attempt should be made to obtain from the older correlational research on aptitude those process hypotheses that seem useful for planning new approaches. Any new study should attempt to represent the network of existing relationships among aptitude measures by including reference ability constructs on its subjects. And, since it is these aptitude measures and constructs that have demonstrated relation to real-world criteria, not the laboratory tasks presently studied, attempts should be made to reference new laboratory findings about aptitude processes back through the network of aptitude tests to the understanding of real-world learning from real-world instruction.

A Research Strategy

To summarize, then, we have chosen three initial activities to guide and elaborate the early stages of theoretical thinking about aptitude processes. One activity tries to milk new meaning out of the old results of factor analytic and related research. Another examines the possibility that eye movement patterns during aptitude performance will reflect process individual differences linked to existing aptitude constructs. The third checks similar possibilities in the use of a standard method of obtaining subject introspections. We hope this exploratory work will provide a sense of the variety and complexity of individual differences in processing that are possibly involved in aptitude performance before one breaks into the phenomena with experimental manipulations. With an exploratory mapping of the terrain, we can then build experimental designs that pin down the details of processing differences.

There is a rough categorization of variables that serves as an initial theoretical framework for our work, and perhaps a few words about this can serve as conclusion for my part of the symposium. Figure 3 identifies these categories and indicates by arrows the direction analysis has taken or can take in the future. Standing predictive relationships between aptitude variables (A) and learning outcomes (O) from instruction have been shown to be moderated by instructional treatment variables (T), with the recognition that ATI often occurs. It is clear that AT combinations can be studied in real instructional settings, and should continue to be, but that this research must be supplemented by analyses conducted in laboratory settings where there is more chance of building theoretical models of psychological processes operating in ATI. The cognitive information processing approach of modern experimental psychology seems best equipped to guide and inform such analyses. But work already completed in our project and elsewhere shows that individual differences in these aptitude processes probably take a variety of complex forms. They are not limited to simple differences in parameters for each processing step. To parallel some distinctions suggested by others as well as our earlier work, a distinction among four major forms or sources of apparent individual differences in processing should help to unravel these aptitude complexes. It appears that individuals can differ in parameters (p) reflecting efficiency and capacity in particular processing steps or com-

ponents, in how a sequence (q) of processing components is organized, in the inclusion of different components or processing routes (r), and in the overall summation (s) of assembly and adaptation of processing to particular tasks. These forms are indicated as p, q, r, and s variables in Figure 3.

Insert Figure 3 about here

Research designed to fill in this framework will need to combine multivariate experimental and correlational methods in a general S-R-R paradigm, wherein stimulus conditions are manipulated to test R-R relations by controlling or modifying them. To reach this point, the requirements of parsimony and construct validation demand the inclusion in such research of multimethod measurement and a representative set of reference factors. To do this, however, a sense of the complexity of this whole network is needed. The work reported in this symposium is designed to do this, at least in a preliminary way.

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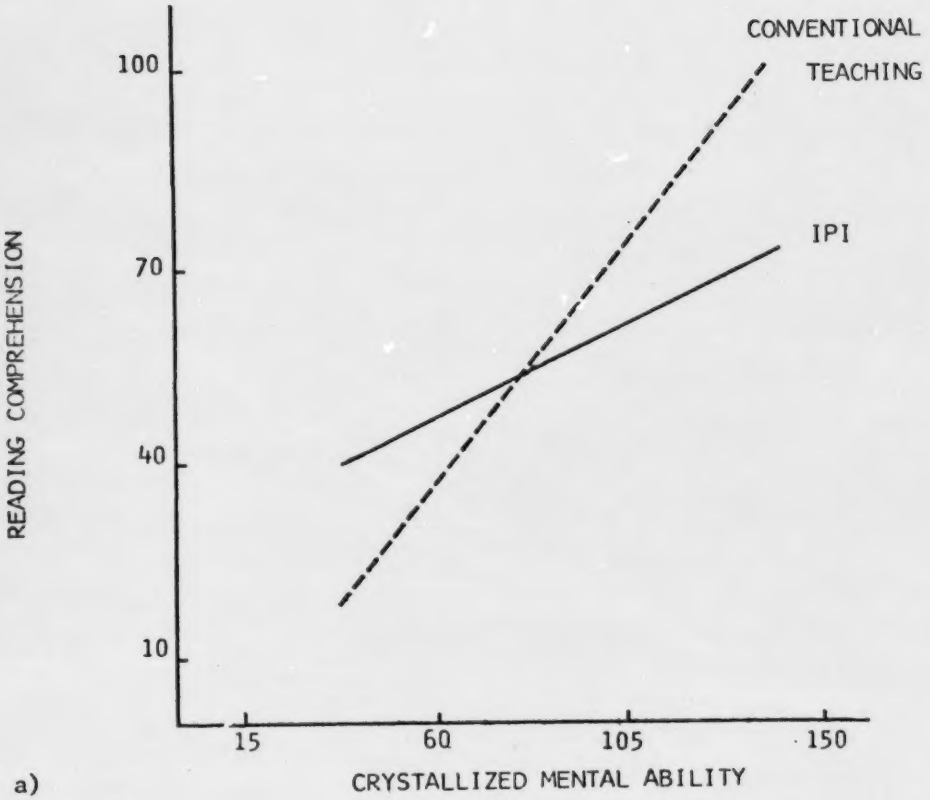
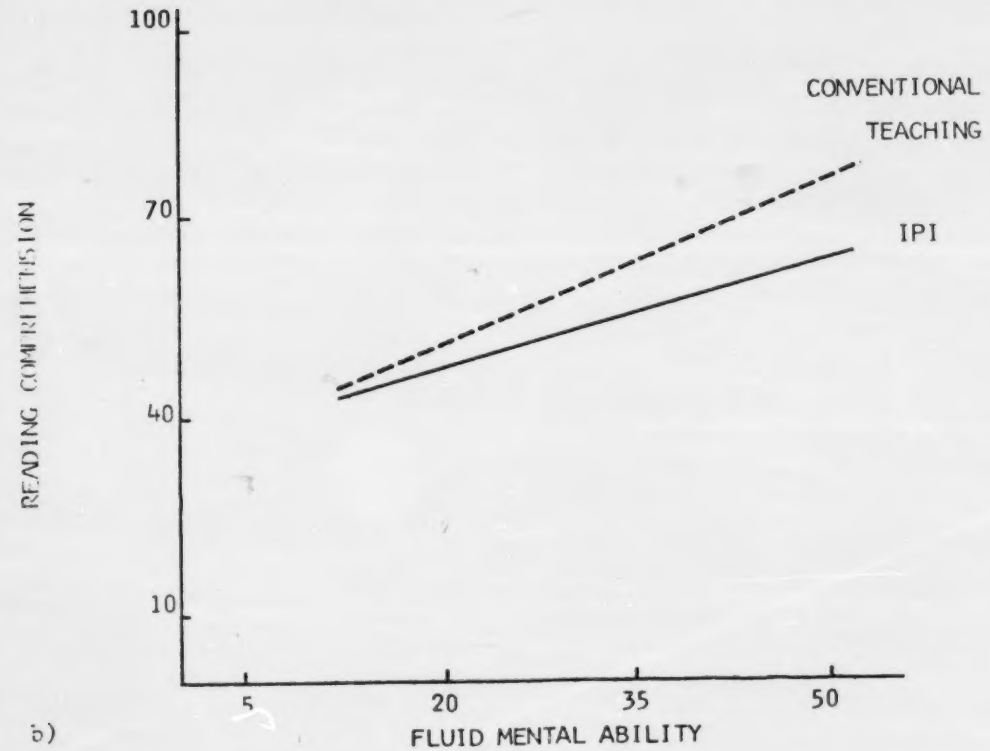


a)



b)

FIG. 1 INTERACTION OF CRYSTALLIZED ABILITY a) AND FLUID ABILITY b) WITH TWO INSTRUCTIONAL TREATMENTS USING READING COMPREHENSION AS OUTCOME MEASURE (AFTER SHARPS, 1973).

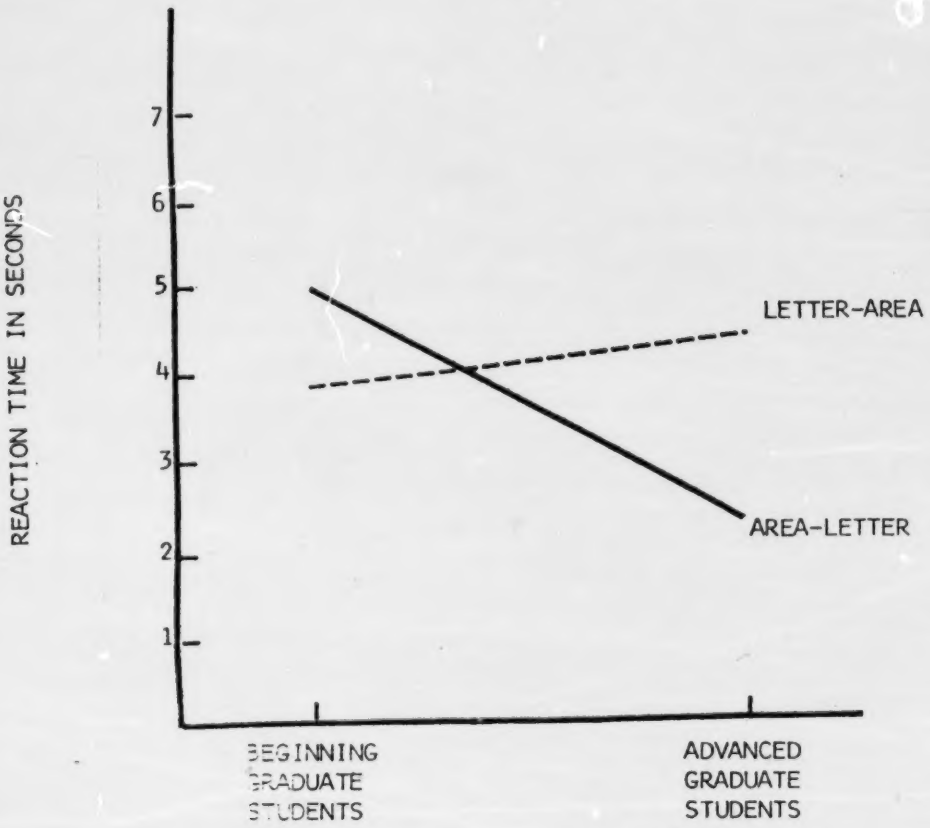


FIG. 2 REACTION TIME FOR BEGINNING AND ADVANCED STUDENTS TO PRODUCE A PSYCHOLOGIST'S NAME UNDER TWO ORDERS OF STIMULUS PRESENTATION (LETTER-AREA; AREA-LETTER). (DATA FROM LOFTUS AND LOFTUS, 1974, 1976).

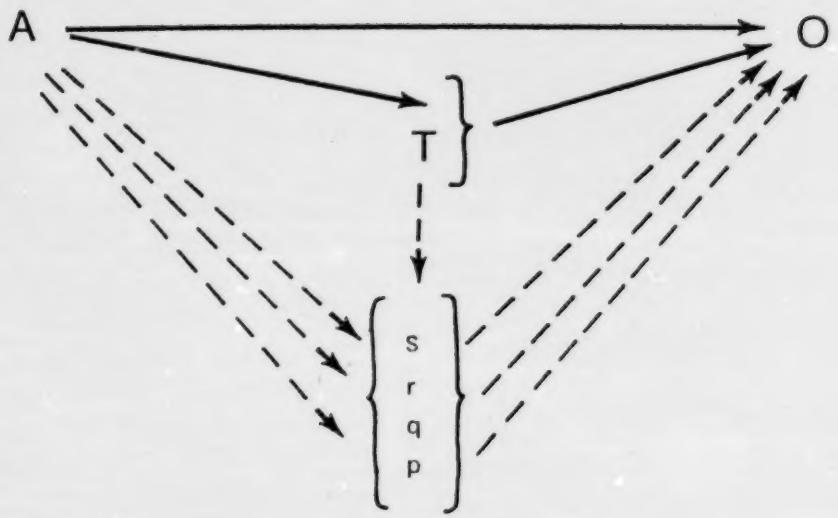


FIG. 3 SCHEMATIC REPRESENTATION OF STANDING CORRELATIONS BETWEEN APTITUDE (A) AND OUTCOME (O) VARIABLES, A x TREATMENT (T) INTERACTIONS, AND THE ANALYSIS OF A AND T VARIABLES INTO INFORMATION PROCESSING VARIABLES. BRACKETS INDICATE COMPLEX INTERACTION.